



Conceptual Design for a Coal Mine Gob Well Flare



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**Coalbed Methane Outreach Program
Atmospheric Pollution Prevention Division
U.S. Environmental Protection Agency**

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1.0 INTRODUCTION

Currently, about 30 U.S. coal mining operations employ a system of degasification to assist in reducing the emission of methane into their mine ventilation systems. All but one of these mines utilize vertical gob wells as a form of degasification. This is an effective technique for longwall coal operations, particularly if a vacuum is applied to the wellhead using a mechanical prime mover such as a liquid seal extractor or blower/exhauster (an active as opposed to passive system). In most cases, gas recovered from gob wells is discharged directly to the atmosphere. Not only does this pose safety and environmental concerns, but it is a waste of a potential resource.

In the U.S. there are no standards for equipping actively extracted or passive gob wellheads. Some active installations are fitted with flame arresters, backflow check valves, and monitoring and control systems, while others may feature only a short vent stack with minimal ancillary equipment. Passive gob wells have, under certain situations, reversed flow and supplied intake air to the gob. As coal mines extend farther under public lands and as residential areas continue to spread out from urban zones toward coal mines, gob wellhead safety becomes more of a concern, not only for the protection of the public, but for the mine as well.

From an energy perspective, the most viable solution would be to recover the gob gas at the wellhead for utilization. However, because of technical and economic circumstances, this is not always possible. In these cases, both safety and environmental objectives could be satisfied by flaring the emitted gas. An active, controlled system of flaring, similar to that used in other industries, is proposed.

This report presents a conceptual design for a flare system for a single actively extracted longwall gob well. This concept is intended to be applicable to mines where for either technical or economic reasons, it may not be possible to utilize the gas recovered. The objective of this project is to develop a flare that would be suitable for igniting methane-air mixtures extracted from coal mine gob wells, with particular concern to eliminating the possibility of a confined deflagration and/or detonation through the flare system and/or gob well and mine.

1.1 Benefits of Methane Flaring

Gas flaring is a standard safety practice in many industries. For example, methane and other associated gases are routinely flared during processing and production of oil and gas, and are continuously flared from landfill collection systems. The petroleum industry flares for safety reasons during system upsets when high concentrations and volumes are released in the vicinity of potential sources of ignition. In the landfill industry, methane constitutes approximately 50 percent of the gas recovered. Flaring is conducted to combust it and other associated toxins (hydrogen sulfide and non-methane organic compounds), which are ground-level ozone build-up gases. Unlike landfills, coal mine gob gas consists of a methane mixture in air and does not contain many toxins.

1.1.1 Mine Benefits

Incorporating a controlled flare system would minimize the potential of an unconfined deflagration occurring on surface at the gob well discharge location, brought about by natural or man-made sources. This would mitigate risk to the public as well as the underground mine.

Recommended design practices for gob wellheads, with options for incorporation of an active flare system, would improve the current level of gob wellhead safety in the U.S. and minimize the implementation of passive gob wells, which may be susceptible to air reversal.

In addition, the concern of introducing mine intake air of higher methane background concentrations would be minimized. Localized air supply shafts, driven to connect main entries more closely to longwall workings, may now be viable to mine operators with constrained mine ventilation systems.

Continuous monitoring provisions, necessary with a gob well flare, would provide uninterrupted records of gob well performance. These would be valuable in comparing gob well production with underground conditions, and investigation of mine incidents such as mine fan failures, changes to the ventilation system, or accidents. Currently most active gob wellhead installations do not use continuous monitoring equipment.

1.1.2 Environmental Benefits

As the global warming potential of methane is approximately 24.5 times that of CO₂ (over a 100-year time frame), combusting the methane released from coal mines using an active and controlled flaring system, would result in emission of a significantly less harmful gas (IPCC, 1994). Flaring 35 percent of the methane emitted from just one of the gassiest coal mines in the U.S. would result in an emission reduction, based on CO₂ equivalent, of one million tons annually. Flaring coal mine methane would then alleviate local air quality problems in many cases. Additionally, methane contributes to tropospheric ozone problems.

A controlled flare system is proposed with redundant safety features, a prime gas mover, an elevated stack, a controlled pilot, and a continuous monitoring system.

1.2 Mine Safety and Health Administration (MSHA) Response Request

The conceptual design for an active, controlled and monitored, single gob well flaring system was developed for presentation to MSHA. The Coalbed Methane Outreach Program anticipates that MSHA will view favorably a gob well flare design incorporating standard practices and safety features recommended by the American Petroleum Institute.

2.0 PROPOSED FLARE DESIGN

This section presents a conceptual design of a flare system, suitable for application to a single, actively extracted gob well. The concept design is also suitable, with some modification, for connection to a multiple gob well gathering system. This application could be investigated following field performance verification of a single gob well pilot.

2.1 Design Parameters

Gob well flare system design parameters were derived using typical gob well performance characteristics.

2.1.1 Methane Concentration

The flare system was designed for combustion of methane concentrations (in air) ranging from greater than 30 percent to 100 percent by volume. At a methane concentration of 30 percent by volume the flare will be by-passed (see Monitoring and Control, Section 2.4.4).

2.1.2 Gas Flow Rate

The flare design was developed to accommodate a variable range of gas flows (methane and air mixture) extracted from a typical gob well by a blower/exhauster. Gas flows ranging from 20 mscfd to 2 mmscfd (14 to 1400 scfm) were specified. At high gas flows, high methane concentrations are expected, while lower methane concentrations are expected at lower gas flows.

2.1.3 Gas Heating Values

Flare performance was specified for gas heating values ranging from 300 Btu/scf to 1000 Btu/scf based on pure methane concentrations in air.

2.1.4 Flare Location

For this design, the flare was assumed to be located in areas that are not designated by the EPA as “ozone non-attainment areas”, or where noise or luminance ordinances are imposed.

2.2 Applicable Codes and Guidelines

Applicable codes and guidelines for utility, landfill, and flares used in the petrochemical industry were incorporated in the gob well flare design.

2.2.1 40 CFR 60.18 General Control Device Requirements

These are control requirements to achieve EPA air emission standards and specify the following:

- No visible emissions (except for 5 minutes every 2 hours)
- Flame presence at all times when emissions are vented
- Minimum gas quality (200 Btu/scf - unassisted flare)
- Maximum gas exit velocity as a function of flare type and gas quality (60 fps unassisted, variable quality)
- Flares must be monitored for design conformance
- Pilot flame must be continuously monitored

2.2.2 Industry Handbooks

The following applicable guidelines were provided from flare gas systems handbooks.

Flare Height: The height of the flare is based on ground level limitations on thermal radiation intensity as determined from maximum gas flows and heating values, including wind factors for a 20 mph speed. Limiting radiation intensities are:

- 440 Btu/hr-ft² unlimited time exposure by personnel
- 3000 Btu/hr-ft² maximum at base of flare
- 1500 Btu/hr-ft² minimum fenced boundary limit
- 750 Btu/hr-ft² maximum at property lines
- 1500 Btu/hr-ft² digital equipment and controls

Noise: Noise emissions result from combustion of the turbulent gas stream. The emitted decibel level is proportional to the second power of the quantity of the hydrocarbon burned. In populated areas, a closed flare system may be necessary to reduce noise emissions.

Luminance: Sufficiently mixed air and fuel gases will burn with a blue non-luminous flame. If insufficient mixing occurs, the flame will become luminous. Where luminance is a concern, an assisted or closed flare system is recommended (Section 2.3).

2.2.3 American Petroleum Institute (API) 931, *Manual on Disposal of Refinery Wastes Volume on Atmospheric Emissions*, Chapter 15 - Flares, and API Recommended Practices (RP) 521

Guidelines for flare flash-back protection design are provided by API. Flare flash-back protection is achieved by either (1) ensuring a minimum purge gas flow at all times out the stack, or (2) incorporating a passive protective system that mitigates air inflow into the top of the stack, in addition to (3) incorporating a liquid seal, which effectively arrests flame and detonation propagation upstream of the flare stack.

Purge Gas Requirement: A purge gas flow prevents air from entering back down into the stack due to wind or thermal effects (caused by ambient air and gas density differences during low stack flows) and potentially creating an explosive mixture.

Gas Seals: Gas seals, commonly denoted as fluidic, or diode seals, are recommended to reduce the purge gas volume flow requirements. These seals are typically comprised of stacked conical orifices installed inside the flare stack below the burner tip. The gas seals successfully impede vortex back-flow generated by wind or thermal effects.

Liquid Seal: API recommends the use of a liquid seal at the base of the flare stack to prevent flame and detonation propagation upstream. The gas process stream is introduced via a header into a vessel typically containing an ethylene glycol - water mixture and is discharged through a submersed perforated diffuser. With this system, the gas is released as a series of distinct bubbles with liquid intervals between them, which ensures mitigation of flame propagation through the seal. Standards require a minimum liquid head of 6 inches above the diffuser outlet. A maximum of 12 inches is recommended as gas pulsation occurs at higher liquid levels. API RP 521 also recommends that the gas inlet header height above the liquid level be at least 1.5 times the diameter of the header. This is required in order that a seal be maintained should a vacuum form inside the header as a result of sudden gas cooling during discharge. The total volume of fluid in the vessel must also be equivalent to a minimum of 10 feet of the gas inlet line. Should a detonation occur in the stack, the liquid volume is displaced into the inlet header, providing a minimum 10-foot water seal in the line separating the flare from the rest of the system.

In addition, the height of the vapor space above the liquid line should be a minimum of twice the diameter of the vessel in order to allow for disengagement of entrained liquid before gas entry into the stack.

2.3 Proposed Gob Well Flare Characteristics

The following characteristics were stipulated for the gob well flare system. They incorporate the design parameters and Petroleum and Landfill Industry guidelines and regulatory criteria.

2.3.1 Active Flare

Only an active gob well flare system should be employed. A mechanical blower/exhauster, as is typically fitted to an equipped gob wellhead assembly, will maintain a positive gas pressure and serve as the prime gas mover.

2.3.2 Open Flare

An open flare, where gas is burned at the tip of an elevated stack at combustion efficiencies of 98 percent, is more suitable for a gob well application than an enclosed ground-level flare. Enclosed ground-level flares are used typically at landfills and burn low quality gas more efficiently and emit less NO_x (suitable for use in EPA-designated "ozone non-attainment areas"), but have higher capital and operating requirements.

2.3.3 Unassisted Flare

Because of the readily combustible and lower heat content methane-and-air mixture extracted from a typical gob well, an assisted flare system, where steam or air is injected at the burner tip to promote mixing and therefore enhance combustion, is not required. Instead, an unassisted flare with continuous burning pilot would readily combust the gob gas without producing significant visible smoke (cooled carbon particles).

2.3.4 Flare Safety Features

A flare design that incorporates all of the API 152 flare protection alternatives is recommended. Operability will be ensured with a continuous monitoring and control system with the capability of activating a system of fail-safe valves.

2.3.5 Flare Tip Diameter

A minimum flare tip diameter of 8 inches is recommended based on the expected gas flow range and the requirements of 40 CFR 60.18.

2.3.6 Flare Height

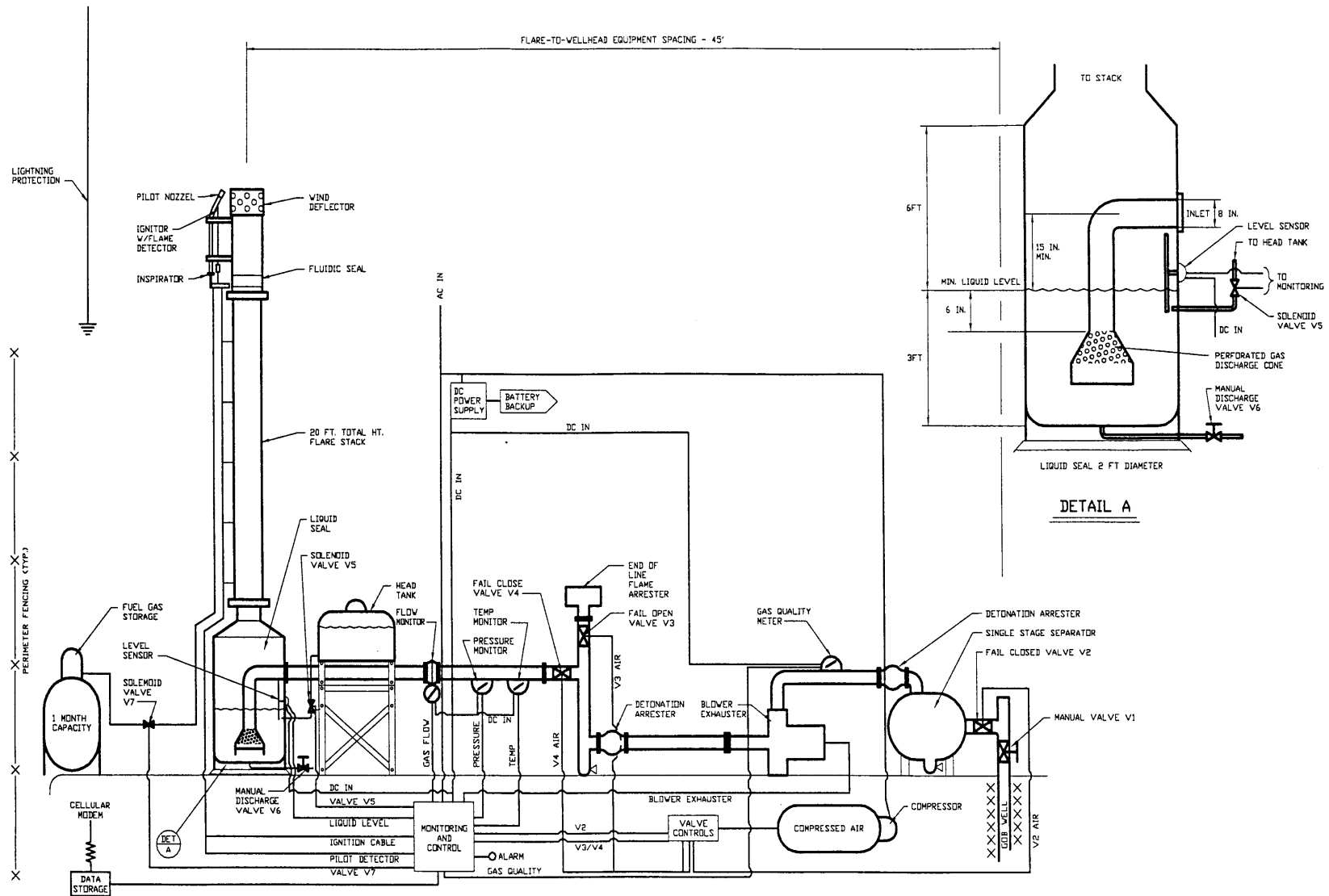
Based on a 1500 Btu/hr-ft² criterion at the base of the stack, a 20-foot overall stack height is specified. The heat distribution profile at grade, based on worst case wind conditions, will be used to establish the equipment (and wellhead) to flare spacing.

2.3.7 Pilot System

A continuously monitored and operating pilot with a separate pilot gas fuel source is recommended.

2.4 Proposed Gob Well Flare Design

A general layout drawing illustrating the proposed gob well flare facility is shown in Figure 1. The facility is comprised of (1) the initial gas processing equipment that is typically in place at an actively extracted gob well, (2) a by-pass gas venting system, (3) the flare, and (4) the monitoring and control system. The monitoring and control system will be capable of activating fail-safe valves and equipment shut-off features. Table 1 provides a detailed list of all components and specifications, including estimated costs.



Component Specification and Costs for Gob Well Flare System						
COMPONENT	MAKE/TYPE	SPECIFICATION	QUANTITY	COST PER UNIT	TOTAL COST	BASIS
Processing Equipment						
Wellhead Assembly	Std. Casing	8 inch Flange	1			Existing *
Shut-In Valve V1	Manual Butterfly	Medium Pressure	1			Existing *
Air Activated Fail Close Valve V2	Actuated Butterfly	Medium Pressure	1	\$ 1,600.00	\$ 1,600.00	
Water Separator/Fines Filtration	Anderson Separators	2 mmscfd max	1			Existing *
Detonation Arrester	Protecto Seal No. 2500	10 in. w.g. max @ 2 mmscfd	2	\$ 7,400.00	\$ 7,400.00	1 is Existing *
Blower/Exhauster	Dry Extractor	0.43 psi min. Pd @ 20 mscfd	1			Existing *
Air Activated Fail Open Valve V3	Actuated Butterfly	Low Pressure	1	\$ 1,600.00	\$ 1,600.00	
Air Activated Fail Close Valve V4	Actuated Butterfly	Low Pressure	1	\$ 1,600.00	\$ 1,600.00	
End-of-Line Flame Arrester	Protecto Seal 860	8 in. Dia. Flange	1	\$ 3,200.00	\$ 3,200.00	S&J Sales
Piping	HDPE	8 in. ID	60 ft	\$6.00 per foot	\$ 360.00	
Flanged Fittings	HDPE	8 in. ID	10	\$ 30.00	\$ 300.00	
Head Tank	150 Gal	Sight Glass - Press. Relief	1	\$ 400.00	\$ 400.00	Estimated
Solenoid Contol Valves V5 and V7	0.25 in. two-position	12 V DC Activated	2	\$ 35.00	\$ 70.00	Skinner
Manual Valve V6	0.25 in	0.25 ID	1	\$ 15.00	\$ 15.00	Estimated
				Subtotal	\$ 16,545.00	
Flare						
Liquid Seal	KALDAIR A-516-70	2 ft ID, 6 ft ht.	1			
Flare Stack	KALDAIR P-8-E	20 ft TOH, 8 inch ID	1			
Pilot and Burner Tip	KALDAIR KEP	Single with Flame Ionization	1			
Pilot Ignition and Cable	KEP-100 w/Nema 4X	220 V AC	1			
				Subtotal	\$22,725	KALDAIR
Monitoring and Control						
Compressor	1 hp Electric	Integrated with 30 gal Tank	1	\$ 800.00	\$ 800.00	Sepor
Valve Controls	Solenoid Valves	12 V DC Activated - 2 Position	2	\$ 98.00	\$ 98.00	Skinner
Monitoring and Control System	Data Logger	8 Channel with DC Activation	1	\$ 3,075.00	\$ 3,075.00	Campbell Scientific
Relay Panel	2 x AC and 4 DC	5 VDC or Manual Activation	6	\$ 600.00	\$ 600.00	Campbell Scientific
AC-DC Power Transformer	With Battery Backup	220 V AC - 12/24 V DC	1	\$ 325.00	\$ 325.00	Campbell Scientific
Liquid Level Sensor	Exp-Proof 2 Wire Trans	6 in. Range, 4-20 mA Output	1	\$ 850.00	\$ 850.00	Davis Instruments
Velocity Sensor	Orifice DP	2, 4, 6 in. ID, 0-1.5 in. w.g.DP	1	\$ 724.00	\$ 724.00	Davis & Davis
Static Pressure Sensor	Static Tap to Manometer	0-25 in. w.g., DC in. 4-20 mA	1	\$ 304.00	\$ 304.00	Cole-Parmer
Temperature Sensor	Thermocouple w/Trans.	0-125 F, DC in. 4-20 mA	1	\$ 150.00	\$ 150.00	Cole-Parmer
Gas Quality Meter	Infrared Gas Monitor	0-100% CH4, DC in. 4-20 mA	1	\$ 3,818.00	\$ 3,818.00	MSA Instruments
Sight Gauges	Magnehelic	0-30 in. w.g., 0-2 in. w.g.	1 Ea.	\$ 125.00	\$ 125.00	Davis Instruments
Air Lines and Conduit		Weatherproof		\$ 300.00	\$ 300.00	Estimate
				Subtotal	\$ 10,869.00	
Facility						
AC Power to Site	220 V AC					Existing *
Site Preparation	Pad for Flare	8 ft Diameter 6 in. Poured	1	\$ 1,000.00	\$ 1,000.00	Estimated
Perimeter Fencing	Cyclone 8 ft.	120 ft				Existing *
Lightning Protection	Rod/Perim.					Existing *
				Subtotal	\$ 1,000.00	
				Total	\$ 51,139.00	
* existing equipment for active gob well						

Table 1: Flare Components and Specifications

2.4.1 Initial Gas Processing Equipment

For a typical extracted gob well installation, a single-stage water separator with fine particulates filtration capability is installed prior to inlet to the blower/exhauster. The separator is equipped with a water discharge tap fitted at the base to release accumulated water. The blower/exhauster, as indicated on Figure 1, typically provides a vacuum of up to - 5 in. Hg at the wellhead and discharges at positive pressures slightly above atmospheric. For the flare system design indicated on Figure 1 and maximum liquid levels in the seal drum, a minimum positive pressure of 0.85 psi is required at the maximum design flow of 1400 scfm, and a minimum positive pressure of 0.45 psi is required at the minimum design flow of 14 scfm.

2.4.2 By-Pass Venting System

As indicated in Figure 1, a by-pass venting system is incorporated in the flare design. Activated valves (see Section 2.4.4) enable the flare to be by-passed and the gas to be vented through an end-of-line flame arrester. For this design, 8-inch nominal internal diameter pipeline is used downstream from the blower/exhauster.

2.4.3 Flare

During normal operations the gas is routed to the base of the flare.

Liquid Seal: The gas is discharged into the liquid seal drum, shown at the base of the flare, through a perforated diffuser, and it is allowed to percolate to the surface of the liquid. The specified liquid is an ethylene glycol - water mixture (50/50), which is maintained at the required level (minimum 6 inches, maximum 12 inches above the diffuser outlet) by a float level control system. The level control system operates an inlet valve through the control panel, as shown on Figure 1. A 150-gallon head tank is provided for a positive pressure supply of water-ethylene glycol which will need to be checked on a routine basis. A manual valve is used for purging or for over-fill conditions as indicated.

Flare Stack: Gas bubbles emanating from the liquid seal surface move to the top of the seal drum and ascend into the flare stack. As shown on Figure 1, the overall stack height was sized at 20 feet with a projected maximum radiation intensity of 1500 Btu/hr-ft² at the base of the stack. This is within the tolerance for digital equipment and controls, although for the proposed design, all controls will be situated at a distance of at least 45 feet from the base of the flare, where radiation intensities of below the 440 Btu/hr-ft² level are projected. This is used as the minimum flare-to-wellhead equipment distance shown on Figure 1 and is based on projected radiation profiles assuming a maximum wind speed of 20 mph. The stack shown on the figure is self-supporting for wind velocities up to 70 mph.

Fluidic Seal: As shown on Figure 1, the stack is equipped with a fluidic seal below the burner tip. For this design, multiple conically shaped orifices are used. With this seal, purge gas flows as low as 0.75 scfm (45 scfh) can be accommodated without air reversal. This is well below the 14 scfm minimum gas flow specified for the design.

Pilot Assembly: The pilot will be supplied by a feed gas source such as a fuel gas storage tank, as shown on Figure 1. For continuous operation, the pilot will require 2.4 mscfd of fuel gas (propane or methane). Air for combustion is introduced into the pilot gas stream through an inspirator located near the flare tip. Pilot operation will be detected using a flame ionization sensor system. This is an industry-accepted detection system and is preferable due to high reliability and low maintenance and operating requirements. Pilot ignition is achieved through an electric ignition cord leading from the control panel and mounted alongside of the stack. Control systems maintain pilot operation at all times except as indicated in Section 2.4.4, Monitoring and Control.

2.4.4. Monitoring and Control

The design incorporates a continuous monitoring system with active control capability.

Sensors: Transmitting sensors will monitor gas quality, static pressure, temperature and flow rate of the process stream, in addition to pilot operation. Analog output from the sensors will be routed to an 8-channel data logger with programmable activation and data recording features.

Control: Power will be supplied to the blower/exhauster, all solenoid valves, and the pilot ignition system, through relays with manual and data logger activation capability. At programmed sensor conditions, the data logger will activate relays as appropriate. The data logger incorporates a cellular modem that enables retrieval of performance data from any computer site.

Fail-Safe Valves: The system design incorporates three principal compressed-air-activated fail-safe valves (V2 through V4 as shown on Figure 1). Compressed air at 80 psia is supplied by small diameter lines connected to a storage tank with integrated compressor. Manual and data-logger-activated solenoid valves are connected to the compressed air lines at the Valve Controls (Figure 1) to either bleed or provide positive air pressure to the actuators.

Control Solenoid Valves: Two additional solenoid valves are incorporated to activate the fuel gas supply (V7) and maintain fluid level control in the liquid seal at the base of the flare (V5).

Manual Operation Provisions: The system will be equipped with manual over-ride provisions and sight gauges for pressure, gas flow and gas quality.

The purpose and normal operating condition (flaring) of all monitoring and control components are itemized in Table 2. The configuration of the fail-safe valves for all modes of operation is presented in Table 3. The process required to achieve each of the operating modes indicated in this table are described in Section 2.4.5 (Flare System Operating Procedures).

Table 4 presents the set points for the proposed sensing equipment and the operation modes activated by the control system should these settings be attained during normal flaring operations.

Table 2: Monitoring and Control System Components and Normal Operating Settings

Monitoring and Control Component	Purpose	Normal Setting
Manual Valve - V1	Well Flow Control and Final Wellhead Shut-In	Open
Compressed Air Activated Fail Close Valve - V2	Facilitates Activation/Shut-in of Well	Pressurized - Open
Compressed Air Activated Fail Open Valve - V3	Flare By-Pass Relief Valve	Pressurized - Closed
Compressed Air Activated Fail Close Valve - V4	Flare By-Pass Relief Valve Actuated with V3	Pressurized - Open
Solenoid Activated Control Valve - V5	Control Liquid Level in Seal Drum	De-Energized - Closed
Manual Control Valve - V6	Manual Discharge of Excess Liquid or Purging Seal Drum	Closed
Solenoid Activated Control Valve - V7	To Activate Fuel Gas Supply Manual	Energized - Open
30 Gallon Compressed Air Tank	Maintains Actuation Pressure on all Compressed Air Control Valves	80 psig
Integrated Compressor	Maintains Air Tank at 80 psig	Off
Compressed Air Activated Valve Controls (Solenoid Valves)	Deactivates Compressed Air to Specific Fail Safe Valves Throughout System	Energized
Methane Quality Sensor	Monitors Methane Gas Concentration in Process Stream	Continuously Active
Gas Flow Sensor	Monitors Actual Process Stream Flow Rate	Continuously Active
Static Pressure Monitor	Monitors for Positive Static Pressure (Blower/Exhauster Operation) and downstream restrictions (liquid seal fluid level)	Continuously Active
Temperature Sensor	Monitors Temperature of Process Stream to Determine Gas Flows at Standard Conditions	Continuously Active
Liquid Level Sensor	Monitors Liquid Level in Seal Drum	Continuously Active
Flame Ionization Detector	Monitors Presence of Pilot	Continuously Active
Pilot Ignition System	Ignites Pilot if Off	Energized
Monitoring and Control System (Data Logger with Recording Capability)	Programmed to Send Signals to Valve Control System and Pilot Ignition Pending Sensor Information	Continuously Active

Table 3: Process Stream Valve Configuration for all Modes of Operation

Mode	V1 Valve	V2 Valve	V3 Valve	V4 Valve
Normal	Open	Open	Closed	Open
By-pass	Open	Open	Open	Close
Shut-in	Closed	Closed	Open	Closed

Table 4: Set Points for Sensing Equipment and Corresponding System Actions During Normal Flare Operation

Sensor	Settings	System Action
Gas Quality	@ 30% Methane in Air @ 25% Methane in Air Max @ 100% Methane in Air	Actuate By-Pass Mode, Alarm De-Energize Blower/Exhauster None
Static Pressure	Min @ 1.0 in. w.g. Normal > 6.3 in. w.g. Max @ 13 in. w.g.	Activate By-Pass Mode, Alarm Alarm if Below Activate By-Pass Mode, Alarm
Gas Flow	Min @ 14 scfm Normal > 20 scfm Max @ 1400 scfm	Activate By-Pass Mode, Alarm Alarm if Below Activate By-Pass Mode, Alarm
Liquid Level in Seal	Min @ 6 in. Above Discharge Normal Range 6 in. to 9 in. Above Discharge Maximum @ 12 in. Above Discharge	Activate Supply Valve None Activate By-Pass Mode, Alarm
Flame Ionization	Pilot Flame not Detected Pilot Flame Detected	Ignite Pilot None

2.4.5 Flare System Operating Procedures

Programmed and manual system operation and control logic for flare start-up and shut-down are presented. Of particular concern during start-up of the system is ensuring sufficient gas flow through the stack prior to ignition of the pilot. Although this could be done automatically, manual system reactivation is recommended when switching from by-pass to flare, and when initiating from the shut-in position. A manual procedure is also recommended for switching the system from normal operations or by-pass mode to shut-in.

Flare Start-Up From Shut-In: The following manual start-up procedure is recommended, initiating with the monitoring and control system set to manual override (refer to Figure 1 and Section 2.4.4, Monitoring and Control):

1. Engage by-pass mode (V4 closed, V3 open)
2. Open V1 and V2
3. Monitor gas quality
 - 3.1 - If gas quality is greater than 30% methane proceed to 4
 - 3.2 - If gas quality is less than 30% methane maintain by-pass mode and assess continued operations
4. Activate blower/exhauster
5. Monitor gas quality again
 - 5.1 - If gas quality is greater than 30% methane proceed to 6
 - 5.2 - If gas quality is less than 25% methane deactivate the blower/exhauster
6. Deactivate by-pass mode (V4 open, V3 closed)
7. Verify flow, static pressure and level indicator

- 7.1 If within tolerances proceed to 8
- 7.2 If outside tolerances reactivate by-pass mode and check system
8. Activate fuel gas supply valve (V7)
9. Activate pilot ignition system
10. Set monitoring system to automatic mode

Flare Start-Up From By-Pass Mode: The following manual start-up procedure is recommended initiating with the monitoring and control system set at manual override (refer to Figure 1 and Section 2.4.4, Monitoring and Control):

1. Verify gas quality
 - 1.1 - If gas quality is greater than 30% methane proceed to 2
 - 1.2 - If gas quality is less than 30% methane maintain by-pass mode and assess continued operations
2. Deactivate by-pass mode (V4 open, V3 closed)
3. Verify flow, pressure and level indicator
 - 3.1 - If within tolerances proceed to 4
 - 3.2 - If outside tolerances reactivate by-pass mode
4. Activate fuel gas supply valve (V7)
5. Activate pilot ignition system
6. Set monitoring system to automatic mode

Normal to By-Pass Mode: The following remote procedure is recommended (refer to Figure 1 and Section 2.4.4, Monitoring and Control):

1. Deactivate pilot ignition system
2. De-energize and close fuel gas supply valve (V7)
3. Activate by-pass mode (V3 open, V4 closed)
4. Signal alarm

Shut-In: The following manual procedure is recommended for shutting-in the gob well from normal flare operating conditions (refer to Figure 1 and Section 2.4.4, Monitoring and Control):

1. Deactivate pilot system
2. De-energize and close fuel gas supply valve (V7)

3. Activate by-pass mode (V3 open, V4 closed)
4. Deactivate blower/exhauster
5. Deactivate (close) shut-in valve (V2)

2.5 Safety Features

Throughout the gas process stream, protection is provided from all potential sources of ignition and from flashback or detonation occurring in the flare stack, via (1) an integrated passive safety system, and (2) an active monitoring and control system.

2.5.1 Isolation of Potential Sources of Ignition

The blower/exhauster and the by-pass vent are two potential sources of ignition within the flare system. As indicated on Figure 1, the blower/exhauster is isolated on either side by in-line detonation arresters. These arresters are designed to stop low speed confined deflagrations and high speed and high pressure flame fronts (sonic detonation and overdriven detonations) in either direction. The design incorporates redundancy as a liquid seal in addition to a detonation arrester is incorporated between the blower/exhauster and the flare. The arresters specified for this design are tested according to API 2000, Underwriters Laboratories 525, and Factory Mutual Research Approval's FM Class No. 6061 standards. The specified in-line units incorporate spiral wound crimped metal (of appropriate lengths and materials) to provide flame quenching. Anticipated pressure losses using a 10-inch diameter unit are 0.35 psi for the largest flow specified for the flare system design.

An end-of-line flame arrester is fitted on the vent by-pass discharge stack to protect the flare system from a flame entering into the system should the by-pass gas be ignited. The arrester specified for this design incorporates a crimped stainless steel foil element and is designed to prevent flash back from unconfined deflagrations.

The flame arresters and their arrangement are typical of gob well installations equipped with blower-exhausting equipment.

2.5.2 Isolation of Potential Ignition from Flare

The proposed design mitigates the potential of flash-back from the flare by incorporating (1) an active positive pressure system, (2) an API-recommended fluidic seal, (3) an API-recommended liquid seal, and (4) a monitoring and control system with valve and equipment activation capability.

Active System: The blower/exhauster is utilized as the prime mover of the gas through the flare system. A positive pressure is maintained between the discharge of the exhauster to the liquid seal. The liquid seal acts as a damper maintaining constant back pressure on the system. A pressure sensor between the blower/exhauster and the liquid seal continuously monitors for positive pressure to detect blower/exhauster operation.

Fluidic Seal: The flare stack incorporates a fluidic seal that prevents inflow of air into the stack with gas flows as low as 0.75 scfm. This is well below the design minimum flow of 14 scfm. As indicated in Section 2.4.4, Monitoring and Control, gas quality and flow rate are measured at the well head and the control system will activate an alarm should flows drop below 20 scfm, and will properly activate valves for by-pass mode should gas flows reach 14 scfm.

Liquid Seal: The flare stack incorporates an API-recommended liquid seal at the stack base, which will stop a confined deflagration and/or a detonation from propagating upstream of the stack. Gas is bubbled through a perforated diffuser maintained at least six inches below a liquid seal. The liquid is comprised of water-ethylene glycol mixture and the level is continuously monitored. A 150-gallon head tank will provide a positive pressure supply of the water-ethylene glycol mixture for the liquid seal. The control system will activate the inlet valve (V5) based on the indication of the water level sensor. A discharge valve is provided for manual activation (V6) should excess liquid levels be detected by visual inspection.

Monitoring and Control System: A continuously operating monitoring and control system, programmed to activate fail-safe compressed air-actuated valves, is incorporated as an active safety measure. Sensors monitor gas quality, blower/exhauster operation, gas flow, and liquid seal level on a continuous basis. Set points for each sensor are programmed into the controller as well as the appropriate valve activation logic. The control system will be able to remotely switch the system from normal operation to by-pass mode. In the case where the system mode of operation is changed, appropriate alarms will identify the tripped sensor. For this design, reactivating the system from by-pass to normal, from shut-in to normal, and from normal to shut-in can only be accomplished by manual operation. This is to ensure proper operating conditions, as well as sufficient gas purge rates prior to flare re-ignition, and to provide the operator the flexibility to determine shut-in at his discretion.

2.5.3 Isolation from Natural and Man-made Sources of Ignition

The proposed facility will be protected from vandalism and unauthorized entry by an 8-foot high perimeter fence. It will be equipped with properly grounded lightning protection comprised of elevated perimeter static wires. Grounding connections will be made to enhance potential equalization to prevent arcing.

3.0 SUMMARY

The conceptual design for a gob well flare conforms to all applicable codes and regulations and was developed incorporating operational and safety guidelines from the American Petroleum Institute (API). System features, including safety, and estimated capital costs are summarized in this section.

3.1 Proposed Gob Well Flare

An open, unassisted flare system, comparable to that used in the petroleum and landfill industries, was selected as the basis for the gob well flare. The design is for single gob well applications, but could be modified for a multiple well system. The flare design incorporates an active mechanical prime mover (a blower/exhauster), and both passive and active safety systems with remote monitoring and control capability.

3.1.1 Prime Mover

A blower/exhauster, as that typically fitted to an actively extracted gob well, ensures that a positive pressure process stream is maintained to the flare during operation. A relay controls power to the prime mover. The relay can be either manually activated (On/Off), or remotely exited (Off only) by the process control system. The process control system monitors for positive pressure downstream of the blower/exhauster, gas flow rate, and gas quality to assess blower/exhauster operation. System start-up, including activation of the blower/exhauster is a manual process for the proposed design. As the prime mover is a potential source of ignition, detonation arresters isolate it from the gob well and the downstream equipment.

3.1.2 Passive Flare Safety System

The gob well flare design incorporates all of the API-recommended safety features. The primary feature designed to mitigate flash-back upstream from the flare is the liquid seal located at the base of the flare stack. Gas from the process stream is discharged through a perforated diffuser into the liquid. The perforated diffuser releases the gas as distinct bubbles with liquid intervals between them. The design incorporates a liquid level sensor monitored by the control system with supply valve activation capability. Recommended liquid minimum and maximum levels will be programmed into the control system. The liquid, which serves to mitigate flame propagation, or to seal the upstream equipment from the flare, is a water-ethylene glycol mixture. The use of liquid seals is standard practice in the petroleum industry where large volumes of gases are flared in a controlled manner during refining system upsets.

Of prime concern during flare operation is the potential for air to flow down the stack during low gas emissions due to wind or thermal effects. This is usually solved by ensuring a minimum gas purge velocity up through the stack at all times. To reduce the purge gas flow requirements, the API recommends the use of fluidic seals below the burner tip. These seals serve to mitigate vortex back-flow down the stack. The gob well flare design incorporates a fluidic seal that reduces the purge flow requirement to 0.75 scfm, which is significantly below the minimum operating design limit of 14 scfm (20 mscfd). The control system will be programmed to activate

the by-pass mode and signal an alarm if process stream flows fall below 14 scfm as measured by an orifice plate velocity sensor.

3.1.3 Active Flare Safety System

The gob well flare design incorporates a continuous monitoring system with active control capability. The design's control system may remotely by-pass the flare and de-energize the blower/exhauster. System start-up and shut-in is a manual process; for this the design includes manual override provisions and sight gauges.

The control system is designed to monitor gas quality, static pressure downstream of the prime mover, process stream temperature and velocity (flow), and the level of the liquid in the seal drum at the base of the flare. Data transmitted from these sensors is input into a data logger programmed for activation based on sensor information. If the sensors detect any of the following (1) excessive back-pressure downstream of the blower/exhauster, (2) that gas flows exceed the design limit of 1400 scfm (2 mmscfd), (3) that the gas quality is below 30 percent methane by volume, or (4) the gas flows fall below the design minimum of 14 scfm (20 mscfd), the control system activates the by-pass mode. If the gas quality drops below 25 percent by volume with the system in by-pass mode, the controls de-energize the blower/exhauster. The control system activates the by-pass mode by excitation of relays connected to solenoid valves that maintain compressed air to the fail-safe system process control valves.

The monitoring and control system design provides visual system alarms and records process stream data continuously during operation. Stored data and system status can be acquired remotely from any modem-equipped terminal.

3.2 **Proposed Gob Well Flare Capital Costs**

This report includes the capital costs for the added infrastructure required to equip a single actively exhausted gob well with a flare system. Future designs may consider connections to multiple gob wells, with slight cost increases for additional gas collection and monitoring and control equipment.

Manufacturers provided the capital costs for the additional processing equipment, the flare, the monitoring and control system, and the additional facility requirements. These costs are itemized in Table 1, and amount to a total of approximately \$51,200 per system, not including installation.

4.0 REFERENCES

American Petroleum Institute Refining Department, *Manual on Disposal of Refinery Wastes Volume on Atmospheric Emissions*, Publication 931, Chapter 15 - Flares, June 1977.

American Petroleum Institute and Refining Department, *Recommended Practices*, Publication 521, 1969.

Banerjee, K., N.P. Cheremisinoff, P.N. Cheremisinoff, *Flare Gas Systems Pocket Handbook*, Gulf Publishing, 1985.

Code of Federal Regulations, Protection of Environment 40, Part 60, Section 18, "General Control Device Requirements", July 1994.

Intergovernmental Panel on Climate Change (IPCC), 1994, *Radiative Forcing of Climate Change, The 1994 Report of the Scientific Assessment Working Group of IPCC, Summary for Policymakers*.

KALDAIR, Inc, "Pipeflare Specifications: P-8-E", May 1995.

Nardelli, R., "The Wide World of Landfill Gas Flares", LFG Specialties, Inc., Cleveland, Ohio.

Stone, D. K., Lynch, S.K., Pandullo, R.F., "Flares. Part I: Flaring Technologies for Controlling VOC-Containing Waste Streams", *Air and Waste Management Association*, Volume 42, No. 3, March 1992.

Straitz, J.F., "Flare Technology Safety", *Chemical Engineering Progress*, July 1987.